Ticks and Tick-borne Diseases 10 (2019) 101274

Contents lists available at ScienceDirect

Ticks and Tick-borne Diseases

journal homepage: www.elsevier.com/locate/ttbdis

Letters to the Editor

Low air humidity increases aggressiveness of ixodid ticks (Acari: Ixodidae) under high ambient temperatures (a preliminary hypothesis)

It has been established that the brown dog tick *Rhipicephalus sanguineus* sensu lato rarely attacks humans (Walker et al., 2000; Parola and Raoult, 2001). Sometimes, however, notable exceptions have been observed, especially in the Mediterranean countries (Gilot et al., 1990; Wilamowski et al., 1999; Otranto et al., 2014). Recently it was experimentally demonstrated that under high temperature conditions all parasitic stages of *R. sanguineus* s.l. ticks increase their aggressiveness towards hosts and readily attach to humans (Parola et al., 2008; Socolovschi et al., 2009). Epidemiological and clinical data summarized by Parola et al. (2008) support the conclusion that warmer weather increases the tendency of this species to attack humans and infect them with rickettsiae. However, the biological mechanisms underlying the observed relationship between temperature and aggressiveness in *R. sanguineus* s.l. remain unknown.

For more than a century, temperature has been recognized as the most important environmental factor influencing all aspects of poikilothermic animals' life (Mednikov, 1977 [2005]). Due to the gradual warming of the Earth's climate taking place at the present time, the temperature factor has become especially important (Gray et al., 2009; Dantas-Torres, 2015). Although air temperature has been considered to be the leading abiotic factor determining all aspects of the lives of terrestrial arthropods, such factors as air humidity, soil moisture and precipitation are also of high importance for ticks (Daniel and Dusbábek, 1994).

We propose that (i) the positive correlation between ambient temperature and tick aggressiveness is not limited to *R. sanguineus* s.l. but is typical of other tick species, and (ii) the elevated aggressiveness of ticks at higher temperatures is mostly driven by reduced air humidity rather than being a direct effect of temperature. Our hypothesis is based on our previously unpublished data and limited published observations of the behavioral patterns on adult *Ixodes* ticks under different environmental conditions.

In May-June of 1966–1969, we collected hundreds of adult *Ixodes persulcatus* ticks (the taiga tick) in mid-highland mixed forests of the Western Sayan Mountains for utilizing these ticks in toxicological tests. The forests were characterized by the high tick abundance (Naumov, 1999). Four experienced persons in protective clothes collected ticks by flagging grass vegetation. The number of ticks collected by the flag and removed from collectors' clothes (the lower and upper parts separately) as well as the air temperature and relative air humidity (RH) before and after collecting were recorded. Our analysis is based on data sets containing at least 400 ticks per sample, collected over 2–2.5 h, which were obtained during the period of highest activity of the adult ticks (the last 2 weeks of May and the first 2 weeks of June). At that time, the height of grass canopy reached up 50 cm. We identified two pairs of samples with different values of air temperature (22–25 °C vs. 27–30 °C) but similar values of RH conditions (94-68%) and one pair of samples with the same values of air temperature (26–30 °C) but sharply differing values of RH (100-76% vs. 68–50%). For each pair, we compared the percentage of ticks on flags and on collectors' clothes and the mean numbers of ticks per collector per hour of collection. Since the numbers of tick collected by individual personnel at the same area during the same collection period follow a normal distribution (according to our data accumulated over many years), we applied the Student's *t*-test in comparing the data sets, wherein the difference was deemed to be significant if $P < 0.05$.

When ticks were collected at lower and higher temperatures but at the same RH, the proportion of ticks removed from collectors as compared with that on flags increased with higher ambient temperatures (20.2% vs. 10.4%). The difference between the samples was highly significant ($P < 0.001$) both in the mean numbers of ticks per person as well as in the numbers of ticks removed from the lower and upper parts of the clothes. We suggest that the ratios of the numbers of ticks collected by flags to those removed from collectors' clothes at different temperatures indicate that the aggressiveness of adult *I. persulcatus* increases at higher ambient temperature, similar to observations on *R. sanguineus* s.l. (Parola et al., 2008). Okulova (1986, pp. 107, 112) also pointed out that the number of adult *I. persulcatus* attacking humans was 2–3 times higher when ambient temperature increased from 20–24 °C to 26–27 °C. The above data support the first element of our hypothesis that the relationship between ambient temperature and tick aggressiveness is typical of a broader range of exophilic tick species.

When evaluating the effect of ambient temperature on tick activity, it is important to keep in mind that air temperature negatively correlates with air humidity. The importance of air humidity for tick vitality has been noted by many researchers under field observations (e.g. Lees, 1946; Kheisin, 1953; Knülle, 1966) as well as in laboratory experiments (Perret et al., 2003; Crooks and Randolph, 2006). In our work when ticks were collected at the same temperatures but at contrasting RH levels, the proportion of ticks removed from collectors as compared with that on flags increased with lower RH (33.4% vs. 20.6%), 56.3% of which were removed from the upper part of collector's clothes. The difference between the samples was highly significant ($P < 0.001$) in the mean numbers of ticks per person as well as in the numbers of ticks removed from the upper part of the clothes. Under conditions of lower RH, two instances of tick attachment to collectors were observed, whereas there were no such cases under other conditions of collecting during all years of our work in the area.

Since elevated temperatures are usually associated with lower RH, which, in turn, increases water loss by ticks, such conditions are expected to favor tick behavior aimed at compensating dehydration. Typically, when air humidity is low, ticks move down to the litter level to restore their water content (moisture-seeking behavior). We speculate that when ticks sense the proximity of a host, they activate an alternative behavioral approach to restoring hydration by expediting their attachment to the host. According to many authors (reviewed by

https://doi.org/10.1016/j.ttbdis.2019.101274
Received 19 April 2019
Available online 16 August 2019
1877-959X/

Kahl, 2018), the water content of the blood ingested by ticks is about 80% or more. In fact, hematophagy is considered as one of the ways for hydration in many groups of blood-sucking arthropods, including ticks (Benoit and Denlinger, 2010).

Our hypothesis about the primary importance of reduced air humidity in the elevated aggressiveness of ticks at higher temperatures is in line with the conclusion made by Okulova (1986, p. 109) that "air dryness noticeably enhances the impact of the temperature factor" on *I. persulcatus* activity. A similar conclusion was made by Herrmann and Gern (2010) for *I. ricinus*. The hypothesis is also in accordance with observations made in mosquitoes, where dryness increased their activity and a combination of low RH and high ambient temperature increased the rate of water loss and stimulated their blood-sucking activity (Hagan et al., 2018). Although an interaction of multiple factors must influence the behavior of ticks when off the host, air humidity seems to be dominant. Precisely controlled laboratory experiments on ticks of different species and stages are required to test the validity of this hypothesis.

The proposed hypothesis readily explains the observed increased aggressiveness of *R. sanguineus* s.l. towards humans in urban environment. Although this xerophilic species has special adaptations for water conservation (Yoder et al., 2006), adequate humidity is a very important factor for its successful existence (Gray et al., 2009), while its opportunities for water replenishment in urban habitats are likely to be limited. Since the development of urban environment is followed by creation of so-called urban heat islands and urban dry islands (Hage, 1975; Cuadrat et al., 2015; Yang et al., 2017), even ticks with low affinity for humans, finding themselves under conditions of high temperature and low humidity have little choice but to aggressively attack any suitable host to avoid desiccation. Taking into account the fact that ticks have become an ubiquitous component of the urban environment (Uspensky, 2017), and that among the tick species inhabiting cities and towns there are many forest species (such as I. ricinus and I. persulcatus) that are very sensitive to reduced air humidity (Shashina and Ioffe, 1980; Uspensky, 2002), it would be reasonable to anticipate an increased risk of tick-borne diseases in urban areas in the near future.

The tick collections were carried out during the author's work at the Martsinovsky Institute of Medical Parasitology and Tropical Medicine, then the USSR Ministry of Public Health. Excellent editorial assistance by Ilia Ouspenski is acknowledged.

References

Benoit, J.B., Denlinger, D.L., 2010. Meeting the challenges of on-host and off-host water balance in blood-feeding arthropods. J. Insect Physiol. 56, 1366–1376.

Crooks, E., Randolph, S.E., 2006. Walking by *Ixodes ricinus* ticks: intrinsic and extrinsic factors determine the attraction of moisture or host odour. J. Exp. Biol. 209, 2138–2142.

Cuadrat, J.M., Vicente-Serrano, S., Saz, M.A., 2015. Influence of different factors on relative air humidity in Zaragoza, Spain. Front. Earth Sci. 3, 10.

Daniel, M., Dusbábek, F., 1994. Micrometeorological and microhabitat factors affecting maintenance and dissemination of tick-borne diseases in the environment. In: Sonenshine, D.E., Mather, T.N. (Eds.), Ecological Dynamics of Tick-Borne Zoonoses. Oxford Univ. Press, New York, pp. 91–138.

Dantas-Torres, F., 2015. Climate change, biodiversity, ticks and tick-borne diseases: the butterfly effect. Int. J. Parasitol.: Parasites & Wildlife 4, 452–461.

Gilot, B., Laforge, M.L., Pichot, J., Raoult, D., 1990. Relationships between the *Rhipicephalus sanguineus* complex ecology and Mediterranean spotted fever epidemiology in France. Eur. J. Epidemiol. 6, 357–362.

Gray, J.S., Dautel, H., Estrada-Peña, A., Kahl, O., Lindgren, E., 2009. Effects of climate change on ticks and tick-borne diseases in Europe. Interdiscip. Perspect. Infect. Dis., 593232 2009.

Hagan, R.W., Didion, E.M., Rosselot, A.E., Holmes, C.J., Siler, S.C., Rosendale, A.J., Hendershot, J.M., Elliot, K.S.B., Jennings, E.C., Nine, G.A., Perez, P.L., Rizlallah, A.E., Watanabe, M., Romick-Rosendale, L.E., Xiao, Y., Rasgon, J.L., Benoit, J.B., 2018. Dehydration prompts increased activity and blood feeding by mosquitoes. Sci. Rep. 8, 6804.

Hage, K.D., 1975. Urban-rural humidity differences. J. Appl. Meteorol. 14, 1277–1283.

Herrmann, C., Gern, L., 2010. Survival of Ixodes ricinus (Acari: Ixodidae) under challenging conditions of temperature and humidity is influenced by *Borrelia burgdorferi* sensu lato infection. J. Med. Entomol. 47, 1196–1204.

Kahl, O., 2018. Hard ticks as vectors – some basic issues. Wien. Klin. Wochenschr. 130, 479–483.

Kheisin, E.M., 1953. Behavior of adult *Ixodes persulcatus* P.Sch. depending on the environmental temperature and humidity. Zool. Zhurnal 32, 77–87 (in Russian).

Knülle, W., 1966. Equilibrium humidities and survival of some tick larvae. J. Med. Entomol. 2, 335–338.

Lees, A.D., 1946. The water balance in *Ixodes ricinus* L. and certain other species of ticks. Parasitology 37, 1–20.

Mednikov, B.M., 1977. Temperature as a factor of development. In: Mednikov, B.M. (Ed.), Selected Works. KMK, Moscow, pp. 103–144 2005, (in Russian).

Naumov, R.L., 1999. The questing activity of the taiga tick *Ixodes persulcatus* infected with borreliae. Parazitologiya 33, 251–256 (in Russian).

Okulova, N.M., 1986. Biological Interconnections in Forest Ecosystems (using Natural Tick-borne Encephalitis Foci As a Model. 'Nauka' Publ. House, Moscow (in Russian).

Otranto, D., Dantas-Torres, F., Giannelli, A., Latrofa, M.S., Cascio, A., Cazzin, S., Ravagnan, S., Montarsi, F., Zanzani, S.A., Manfredi, M.T., Capelli, G., 2014. Ticks infesting humans in Italy and associated pathogens. Parasit. Vectors 7, 328.

Parola, P., Raoult, D., 2001. Ticks and tickborne bacterial diseases in humans: an emerging infectious threat. Clin. Infect. Dis. 32, 897–928.

Parola, P., Socolovschi, C., Jeanjean, L., Biram, I., Fournier, P.-E., Sotto, A., Labauge, P., Raoult, D., 2008. Warmer weather linked to tick attack and emergence of severe rickettsioses. PLoS Negl. Trop. Dis. 2 (11), e338.

Perret, J.-L., Guerin, P.M., Diehl, P.A., Vlimant, M., Gern, L., 2003. Darkness induces mobility, and saturation deficit limits questing duration, in the tick *Ixodes ricinus*. J. Exp. Biol. 206, 1809–1815.

Shashina, N.I., Ioffe, I.D., 1980. Egg development in some species of ixodid ticks (Ixodidae) under conditions of different humidity. Med. Parazitol. 49 (5), 79–84 (in Russian).

Socolovschi, C., Raoult, D., Parola, P., 2009. Influence of temperature on the attachment of *Rhipicephalus sanguineus* ticks on rabbits. Clin. Microbiol. Infect. 15 (Suppl. 2), 326–327.

Uspensky, I., 2002. Preliminary observations on specific adaptations of exophilic ixodid ticks to forests or open country habitats. Exp. Appl. Acarol. 28, 147–154.

Uspensky, I.V., 2017. Blood-sucking ticks (Acarina, Ixodoidea) as an essential component of the urban environment. Zool. Zhurnal 96, 871–898 (in Russian) [English transl.: Entomol. Rev. 2017, 97, 941–969.

Walker, J.B., Keirans, J.E., Horak, I.G., 2000. The Genus Rhipicephalus (Acari: Ixodidae). A Guide to the Brown Ticks of the World. Cambridge Univ. Press, Cambridge, UK.

Wilamowski, A., Bromley-Schnur, H.J., Ioffe-Uspensky, I., Uspensky, I., 1999. Ticks (Ixodoidea) in Israeli towns. In: Robinson, W.H., Rettich, F., Rambo, G.W. (Eds.), Proceedings of the 3rd International Conference on Urban Pests. Czech Univ. Agriculture, Prague, pp. 477–483.

Yang, P., Ren, G., Hou, W., 2017. Temporal-spatial patterns of relative humidity and the urban dryness island effect in Beijing City. J. Appl. Meteorol. Climatol. 56, 2221–2237.

Yoder, J.A., Benoit, J.B., Rellinger, E.J., Tank, J.L., 2006. Developmental profiles in tick water balance with a focus on the new Rocky Mountain spotted fever vector, *Rhipicephalus sanguineus*. Med. Vet. Entomol. 20, 365–372.

Igor Uspensky*
The Hebrew University of Jerusalem, Israel
E-mail address: igorusp.acarina@gmail.com.

* Corresponding author. Present address: 16, Yustman Moshe St., Apt. 65, Jerusalem 9384208, Israel.